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STATIC STABILITY AND FORCE CHARACTERISTICS OF A 0.02-SCALE MODEL OF THE SATURN C-1 LAUNCH VEHICLE WITH APOLLO PAYLOAD FOR MACH NUMBER 0.31

(NAS9-150)

February 1963

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NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

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FOREWORD

The investigation of the static stability and force characteristics of the 0.02-scale Apollo model was conducted under NASA Contract NAS9-150.

This report was prepared by G.E. Frantz of the Columbus Division of North American Aviation, Inc.

ABSTRACT

The static stability and force characteristics of the launch and launch-abort configurations of a 0.02-scale model of the Saturn C-1 launch vehicle with Apollo payload were investigated in the North American Aviation Columbus Division Aeronautical Laboratory (NACAL) Wind Tunnel at Mach number 0.31 and at angles of attack from -4 to 60 degrees.

The normal force characteristics of both the launch and launch-abort configurations were linear with angle of attack up to α = 35 degrees and were essentially unaffected by roll attitude. The pitching moment became nonlinear at about α = 10 degrees.

A high angle-of-attack separation phenomena that occurred at angles of attack greater than 20 degrees caused a sudden increase in side force, yawing moment, and rolling moment.

CONTENTS

ILLUSTRATIONS

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I. INTRODUCTION

A wind tunnel test program has been conducted to determine the static stability and force characteristics of the Saturn C-1 launch vehicle with Apollo payload in the Mach number range 0.3 to 8.0. Tests were performed on an FSL-1 0.02-scale model at Ames Research Center, Arnold Engineering Development Center (AEDC), North American Aviation Trisonic Wind Tunnel (TWT), and North American Aviation Columbus Division Aeronautical Laboratory (NACAL). Results of the tests conducted at Ames, AEDC, and TWT are given in References 3, 4, and 5. This report presents the analysis of the data obtained at the NACAL test facility from 27 November through 29 November 1962. The basic data are presented in Reference 1.

The purpose of the NACAL tests was to determine the low-speed static stability and force characteristics of the launch and launch-abort configurations at large angles of attack.

II. MODEL AND TESTS

MODEL

The 0.02-scale model consisted of the complete launch configuration of the Saturn C-1 launch vehicle with Apollo payload. Details of the model are presented in Reference 6. Two configurations were tested at the NACAL facility, launch ($B_3I_2S_4R_4C_2T_{20}E_{40}$) and launch-abort ($B_3I_2S_4R_4$). Sketches of the configurations tested are presented in Figure 1.

TESTS

The launch and launch-abort configurations were tested at Mach number 0.31, Reynolds number per foot of 2.05×10^6, and at a dynamic pressure of 135 pounds per square foot.

Six-component force data were obtained with a David Taylor Model Basin (DTMB) 1.5-inch TSB-4A balance and a DTMB No. 10 sting. Balance chamber static pressure was recorded and was assumed to represent the actual base pressure acting on the model base. Data were obtained for angles of attack from -4 to 60 degrees and at sideslip angles of 3, 0, -3, -6, and -10 degrees.

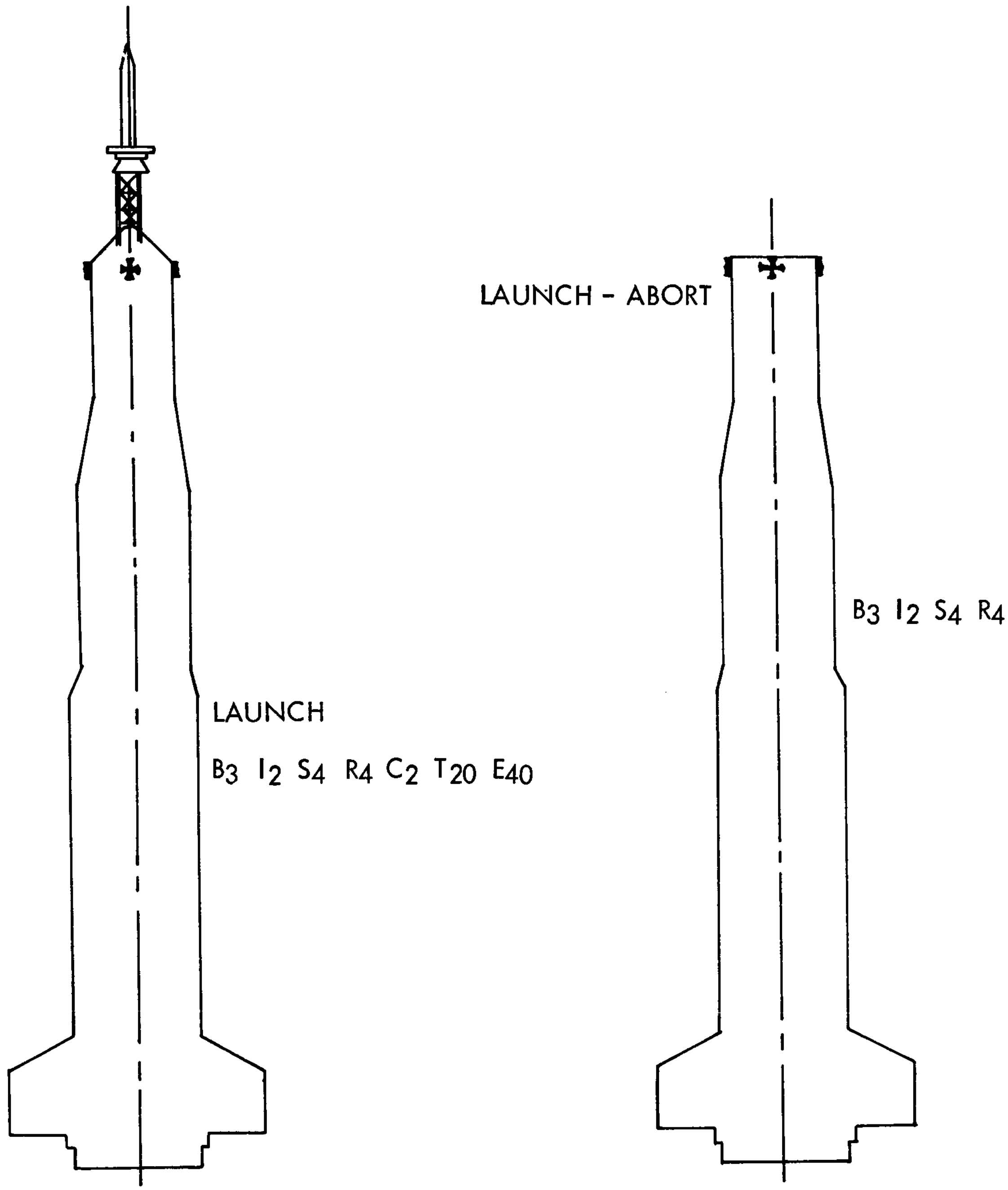

Figure 1. Test Configurations

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III. RESULTS AND DISCUSSION

PRESENTATION OF RESULTS

The aerodynamic coefficients presented herein are referred to the body axis system and are based on booster frontal area (0.1440 ft^2) and diameter (0.4283 feet). The moment reference center, which represents the gimbal axis station, is located 0.389 booster diameters forward of the base (model station 0.00).

Summary results of the aerodynamic characteristics of the launch and launch-abort configurations at α = 0 degrees are presented in the following tabulation. For comparison purposes, results of the TWT test data (Reference 5) at Mach number 0.4 and of the Ames test data (Reference 3) at Mach number 0.7 are also presented.

	Launch Configuration $B_3I_2S_4R_4C_2T_{20}E_{40}$			Launch-Abort Configuration $B_3I_2S_4R_4$		
	NACAL (M = 0.31)	TWT (M = 0.4)	AMES (M = 0.7)	NACAL (M = 0.31)	TWT (M = 0.4)	AMES (M = 0.7)
$(C_{N_\alpha})_{\alpha=0}$	0.120	0.115	0.117	0.122	0.110	0.118
$(C_{m_\alpha})_{\alpha=0}$	0.260	0.240	0.227	0.250	0.210	0.233
$(X_{cp}/D)_{\alpha=0}$	2.554	2.474	2.330	2.439	2.300	2.364
$(C_A)_{\alpha=0}$	0.455	0.435	0.450	0.690	0.645	0.680
$(C_{P_b})_{\alpha=0}$	-0.162	-0.174	-0.158	-0.147	-0.164	-0.160

It may be seen from the foregoing tabulation that the characteristics obtained from the NACAL data are generally greater than those determined from either the TWT or the Ames data. In addition to the different test Mach numbers, the lower test Reynolds number at NACAL may account for the discrepancies between the NACAL and TWT data (particularly in axial force coefficient). The test Reynolds number at TWT for Mach number 0.4 was 8.25 x 10^6 per foot, approximately four times as great as the NACAL Reynolds number.

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EFFECT OF ANGLE OF ATTACK

The variation of the aerodynamic coefficients with angle of attack are presented in Reference 1 and are reproduced herein for β = 0 degrees. The effects of combined α and β (roll attitude) and a discussion of non-linearities at large angles of attack are considered separately.

EFFECT OF ROLL ATTITUDE

Roll attitude was obtained by conducting pitch runs at different sideslip angles. The equivalent roll angle, ϕ, is determined from α and β by the equation $\tan \phi = \tan \beta / \sin \alpha$.

The data were examined in terms of composite normal force ($\bar{C}_N$) and pitching moment ($\bar{C}_m$) coefficients and are presented, as functions of composite angle of attack ($\bar{\alpha}$), in Figures 2 and 3 for the launch and launch-abort configurations. The solid lines in these figures represent data at 0 degrees sideslip angle. Examination of Figures 2 and 3 indicates that except for a few scattered data points the effect of roll attitude is essentially negligible.

NONLINEARITY OF AERODYNAMIC COEFFICIENTS

The variation of normal force coefficient with angle of attack for both the launch and launch-abort configurations is essentially linear up to 35 degrees angle of attack. The pitching moment, however, becomes nonlinear near α = 10 degrees for both configurations.

Figure 4 presents the variation of axial force and base pressure coefficients with angle of attack. Axial force is maximum at α = 0 degrees and decreases continuously with increasing angle of attack. C_A becomes zero at α = 45 degrees for the launch configuration and at α = 55 degrees for the launch-abort configuration. The base pressure coefficient is minimum at α = 0 degrees and increases almost linearly with increasing angle of attack.

As shown in Figure 5, the centers of pressure for the launch and launch-abort configurations are essentially identical at angles of attack below 35 degrees. From α = 35 to 60 degrees, the center of pressure for the launch-abort configuration is about 0.2 diameters farther aft of that presented for the launch configuration. From -4 to 10 degrees angle of attack, both centers of pressure shift aft to a position of 2.3 diameters at α = 10 degrees. As angle of attack is increased beyond 10 degrees, the centers of pressure move continuously forward to a most forward location, at α = 60 degrees, of 2.9 diameters for the launch configuration and 2.7 diameters for the launch-abort configuration.

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Figures 6 and 7 present the variation of side force, yawing moment, and rolling moment coefficients with angle of attack and sideslip for the launch and launch-abort configurations. It may be seen that these data have a relatively uniform variation with angle of attack up to about 20 degrees where a sudden increase occurs followed by an extremely nonlinear variation with angle of attack. Similar side force and yawing moment characteristics have been observed for other bodies tested at low speeds and high angles of attack. Reference 7 contains data for an aircraft fuselage that displayed these characteristics. An investigation of this phenomenon was conducted and the results are reported in Reference 2. It is pointed out that this occurrence is caused by cross flow separation and is a function of cross flow Reynolds number and cross-sectional geometry. A detailed discussion and an attempt to predict these non-linear characteristics are also presented in Reference 7.

[redacted]

$$\overline{C_n} = \sqrt{C_n^2 + C_y^2}$$

$$\bar{\alpha} = \cos^{-1}(\cos\alpha \cos\beta)$$

B ~ DEG.	
——	0
○	3
□	-3
△	-6
◊	-10

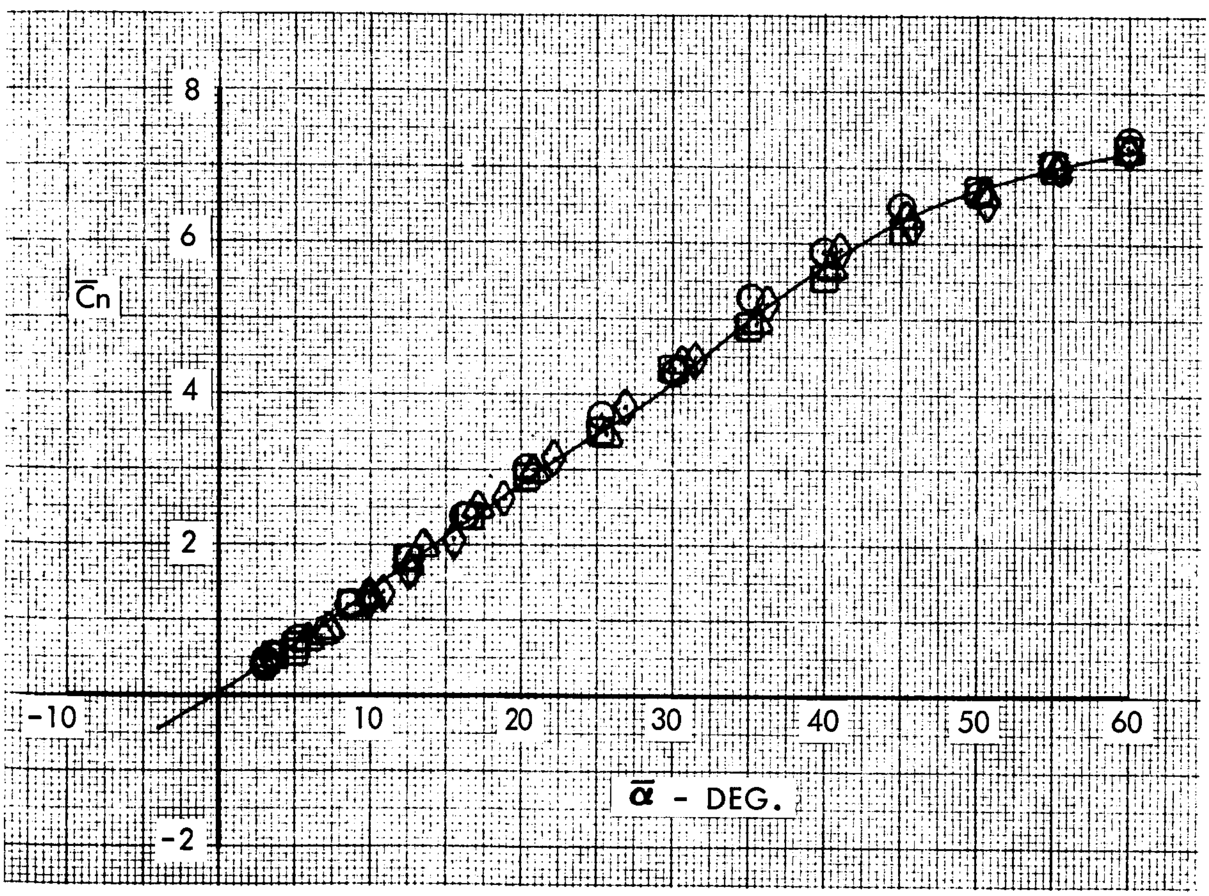

Figure 2. Effect of Angles of Attack and Sideslip on Normal Force and Pitching Moment Coefficients (Launch Configuration) (Sheet 1 of 2)

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$$\overline{C_m} = \sqrt{C_m^2 + C_n^2}$$

$$\bar{\alpha} = \cos^{-1}(\cos\alpha \cos\beta)$$

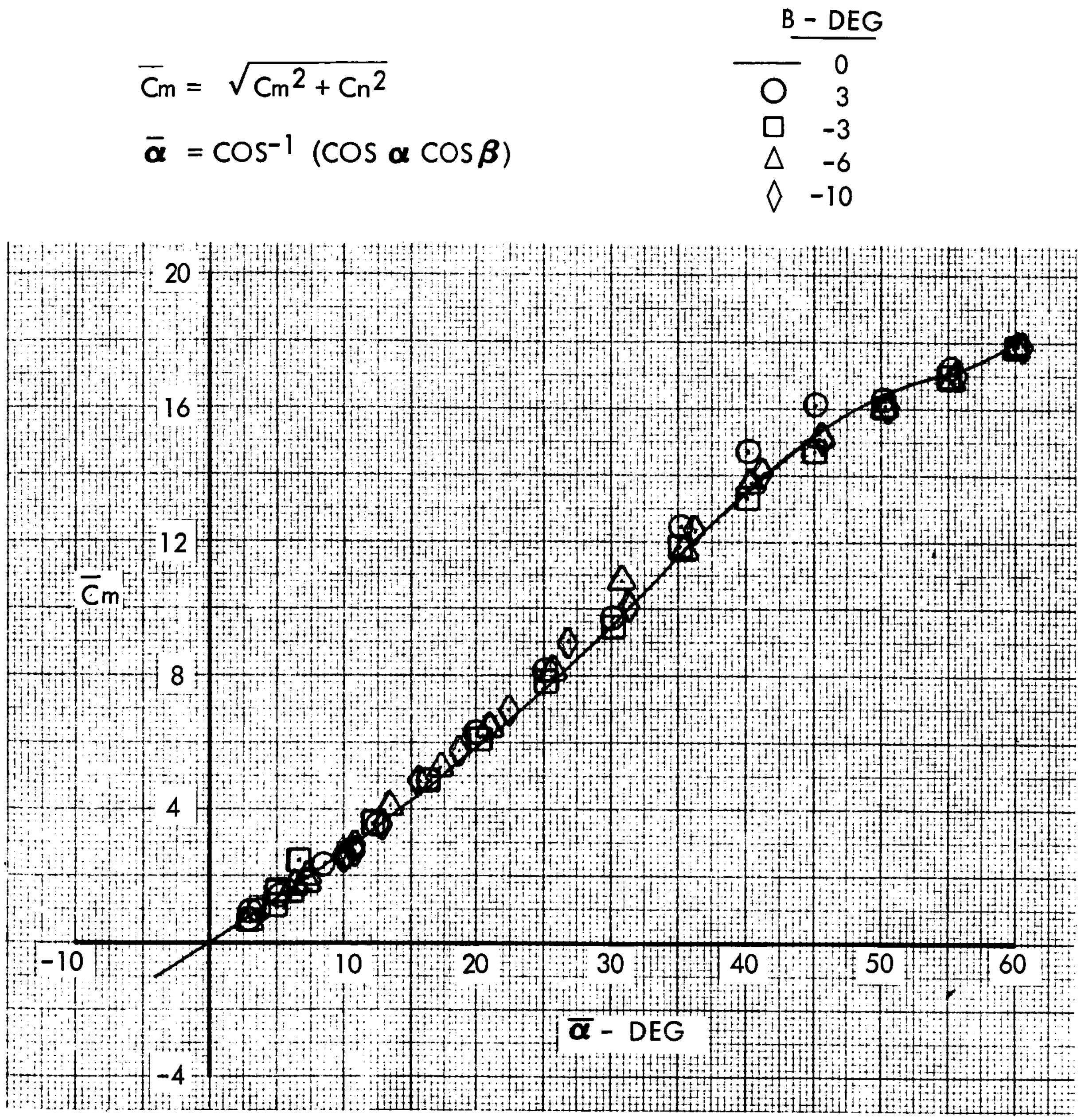

Figure 2. Effect of Angles of Attack and Sideslip on Normal Force and Pitching Moment Coefficients (Launch Configuration) (Sheet 2 of 2)

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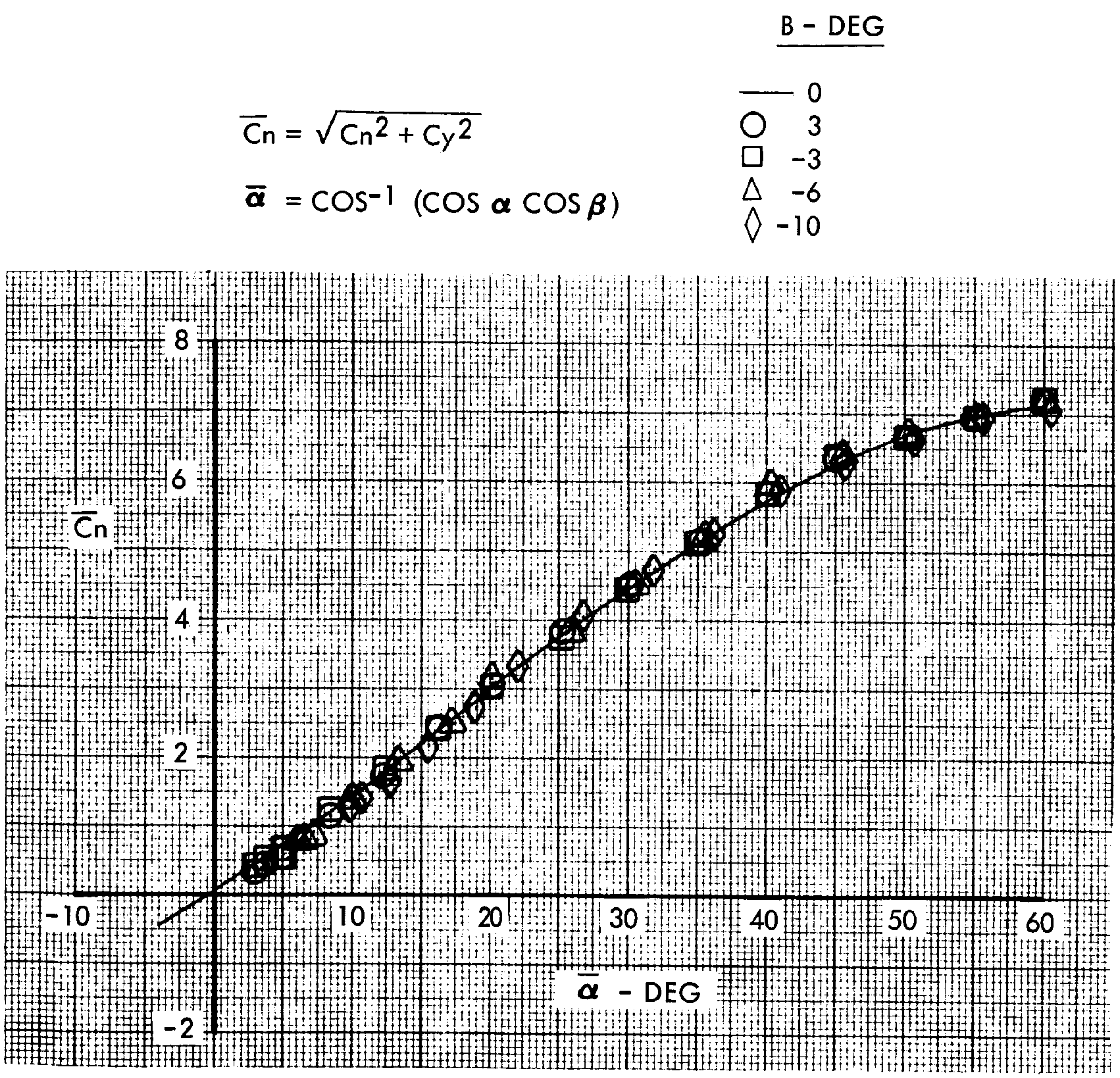

Figure 3. Effect of Angles of Attack and Sideslip on Normal Force and Pitching Moment Coefficients (Launch-Abort Configuration) (Sheet 1 of 2)

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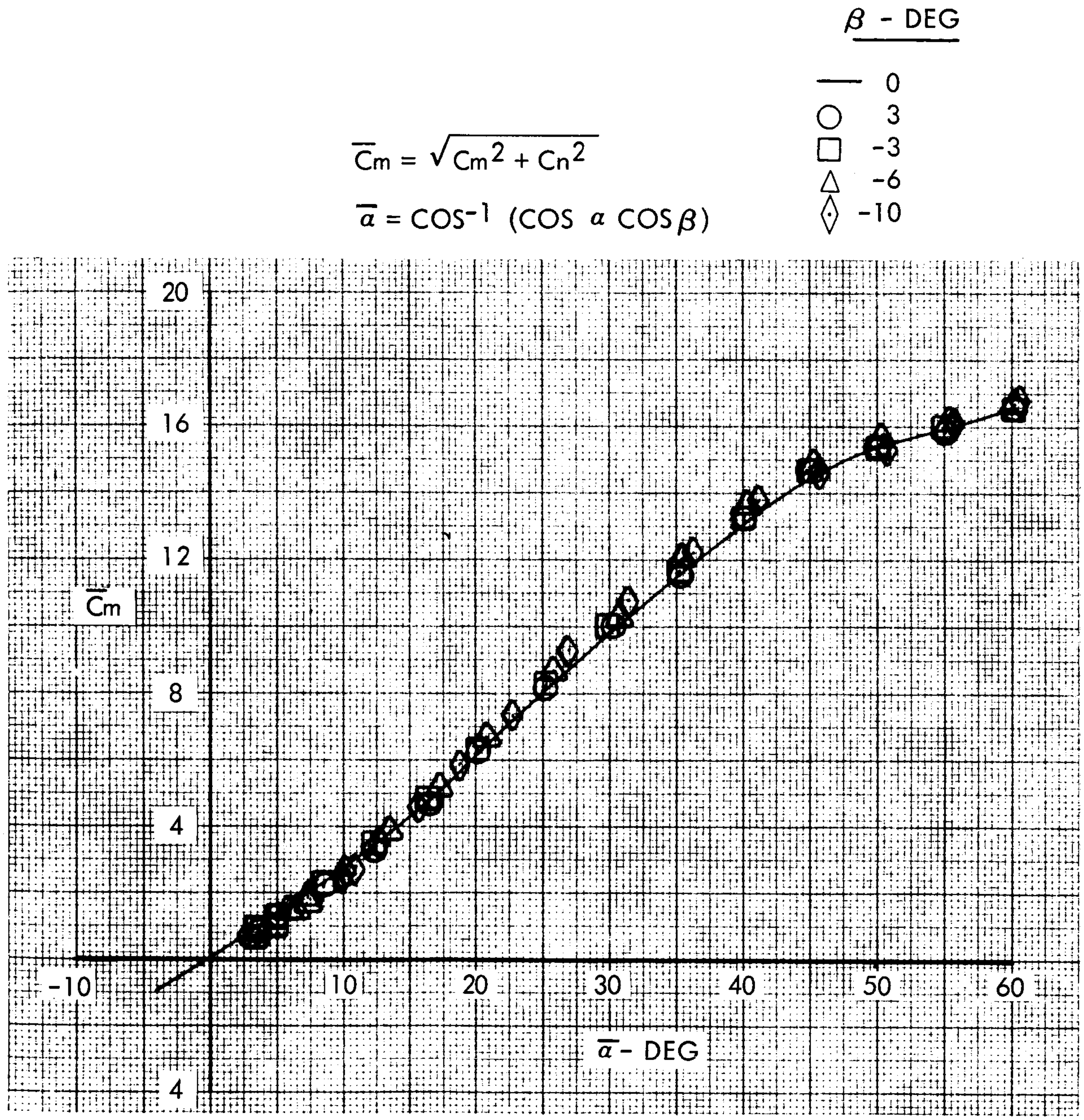

Figure 3. Effect of Angles of Attack and Sideslip on Normal Force and Pitching Moment Coefficients (Launch-Abort Configuration) (Sheet 2 of 2)

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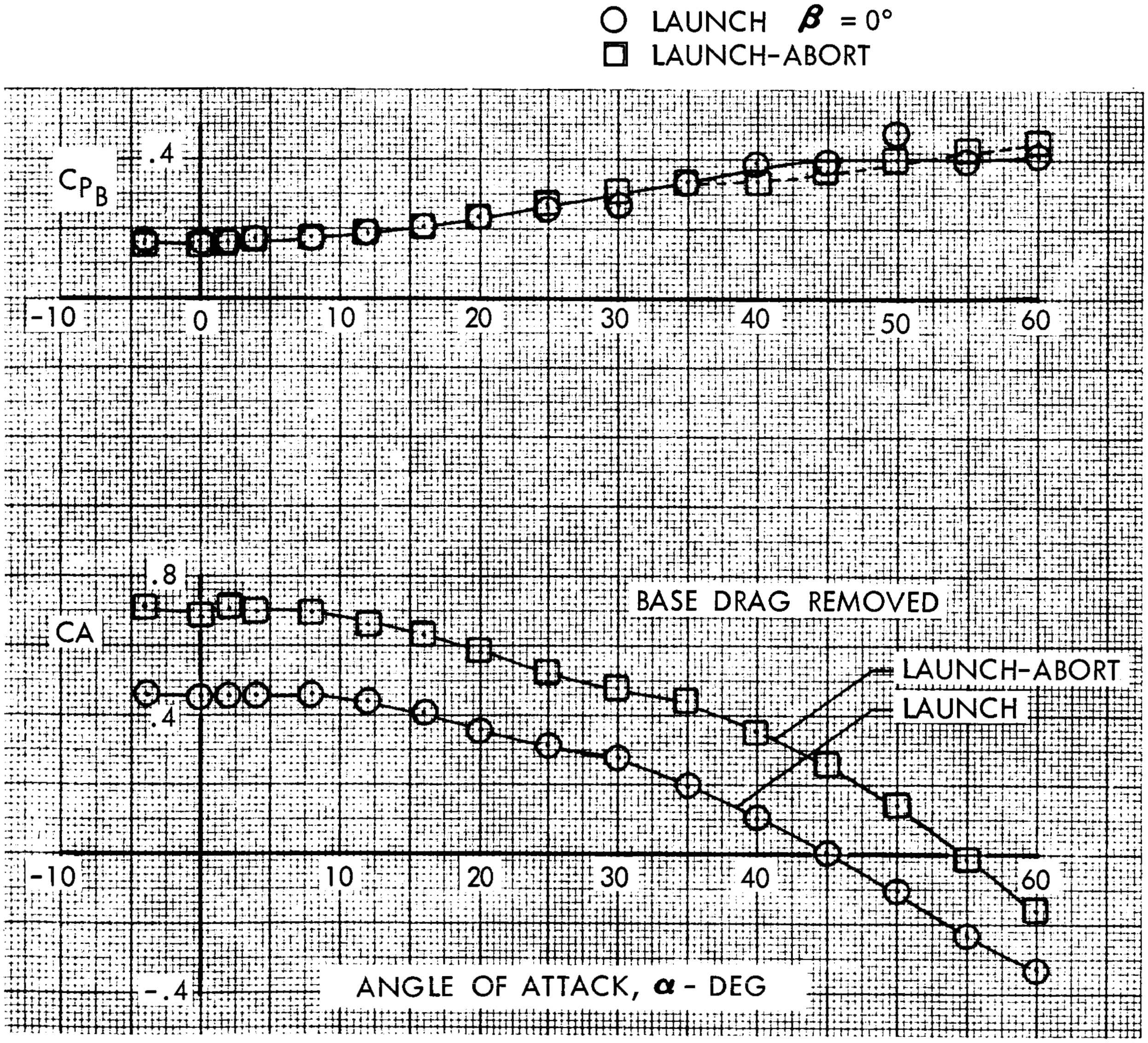

Figure 4. Effect of Angle of Attack on Axial Force and Base Pressure Coefficients for Launch and Launch-Abort Configuration

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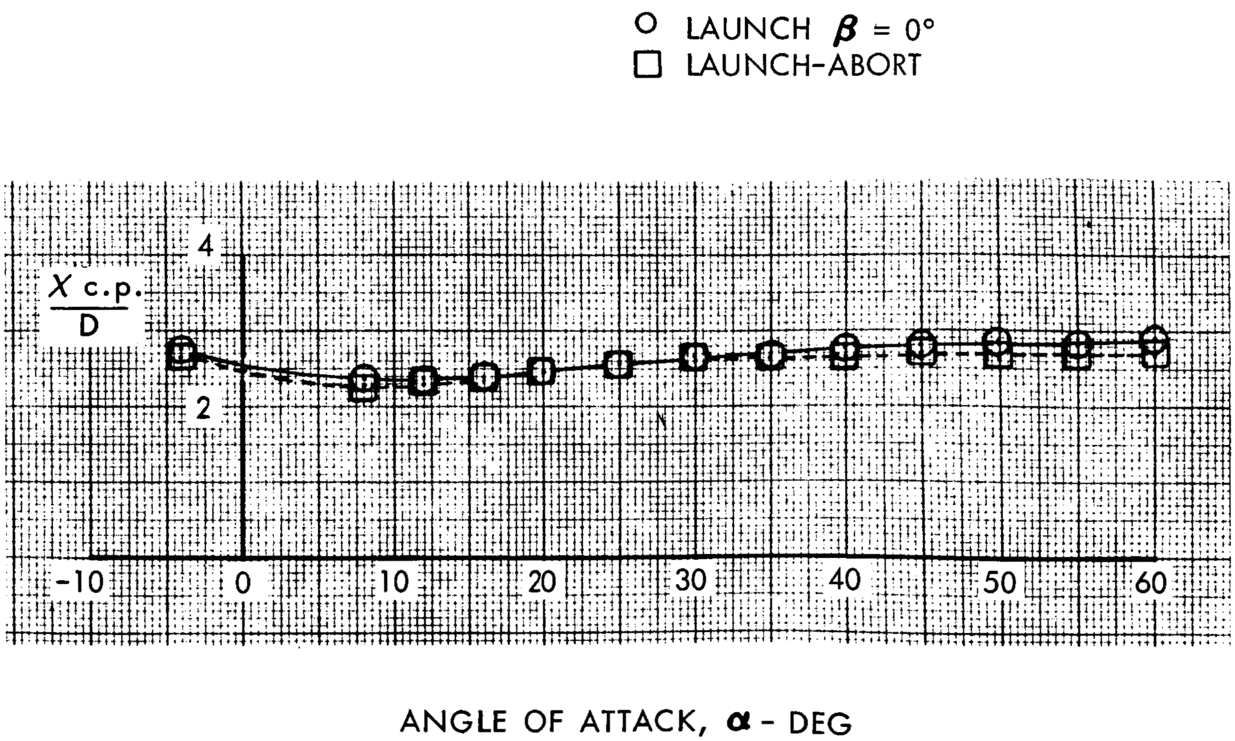

Figure 5. Effect of Angle of Attack on Center of Pressure for Launch and Launch-Abort Configurations

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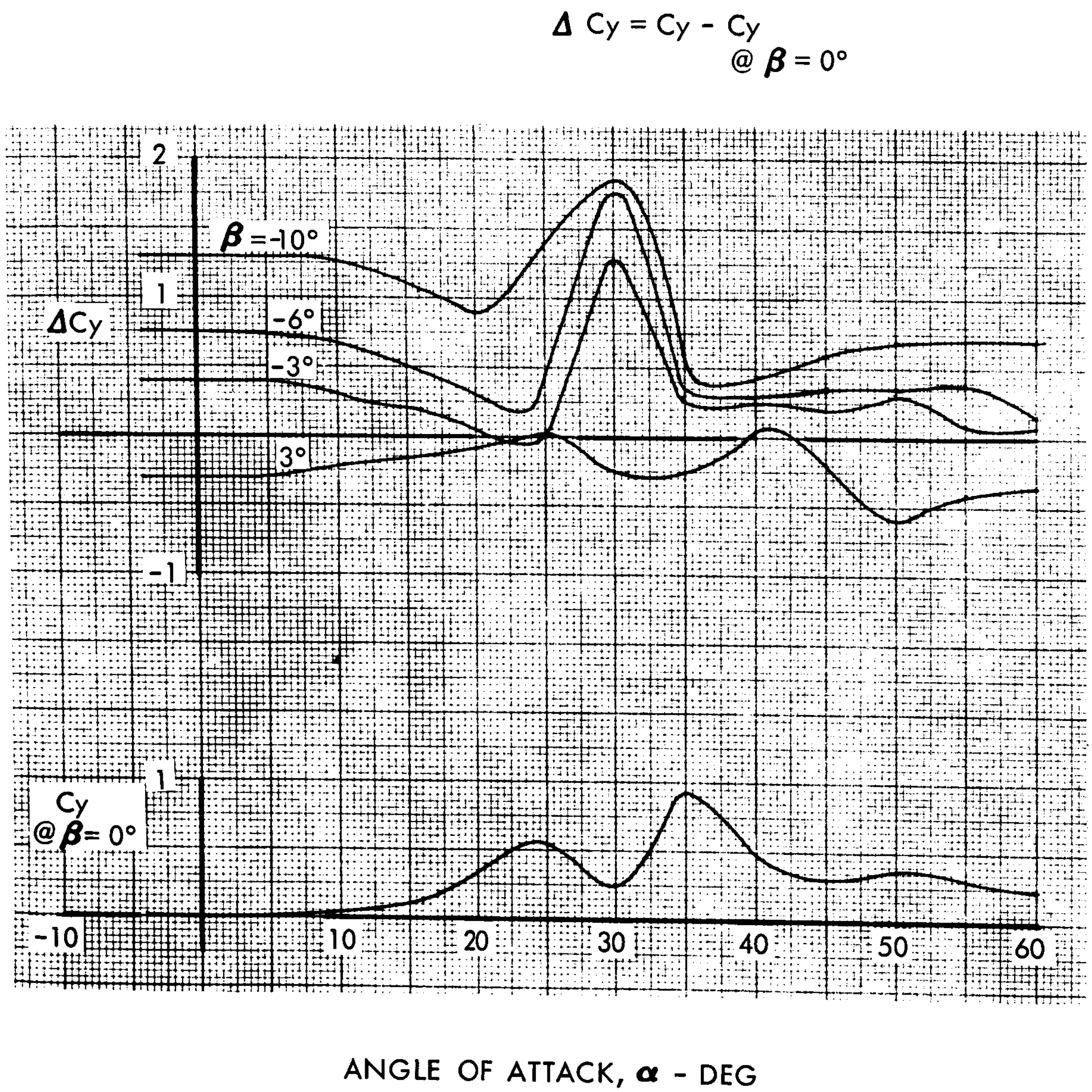

Figure 6. Effect of Angles of Attack and Sideslip on Side Force and Yawing and Rolling Moment Coefficients for Launch Configuration (Sheet 1 of 3)

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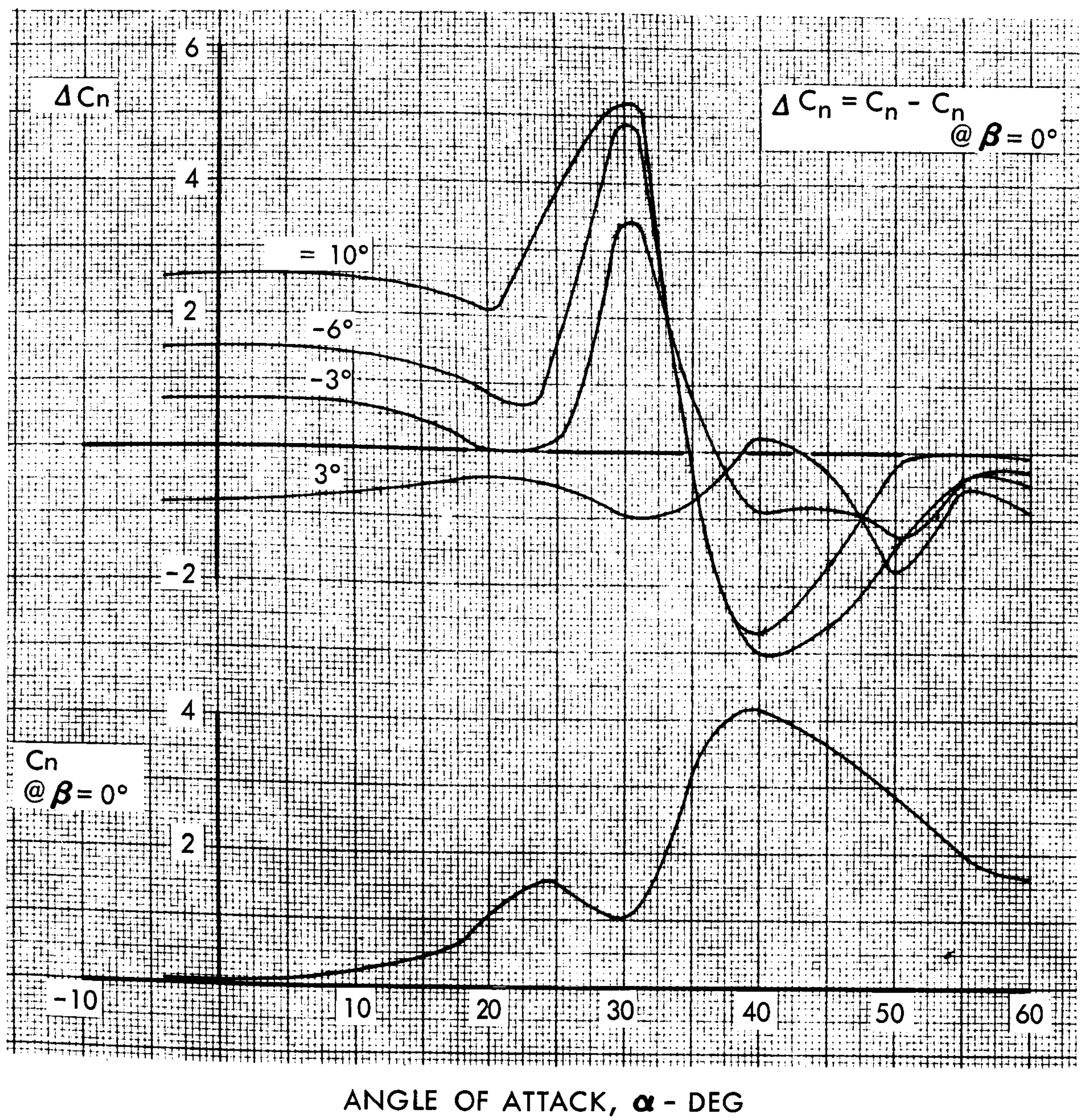

Figure 6. Effect of Angles of Attack and Sideslip on Side Force and Yawing and Rolling Moment Coefficients for Launch Configuration (Sheet 2 of 3)

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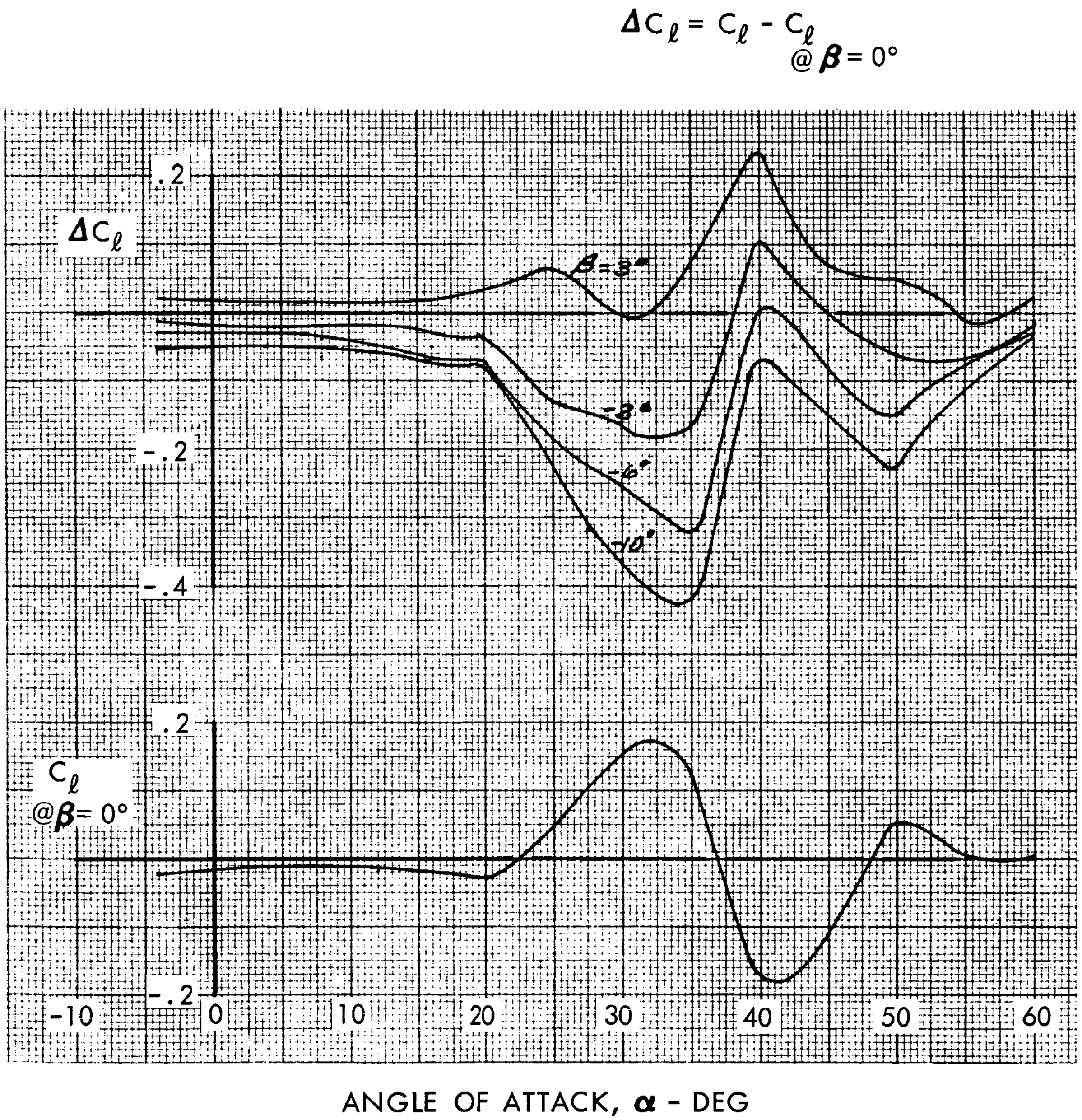

Figure 6. Effect of Angles of Attack and Sideslip on Side Force and Yawing and Rolling Moment Coefficients for Launch Configuration (Sheet 3 of 3)

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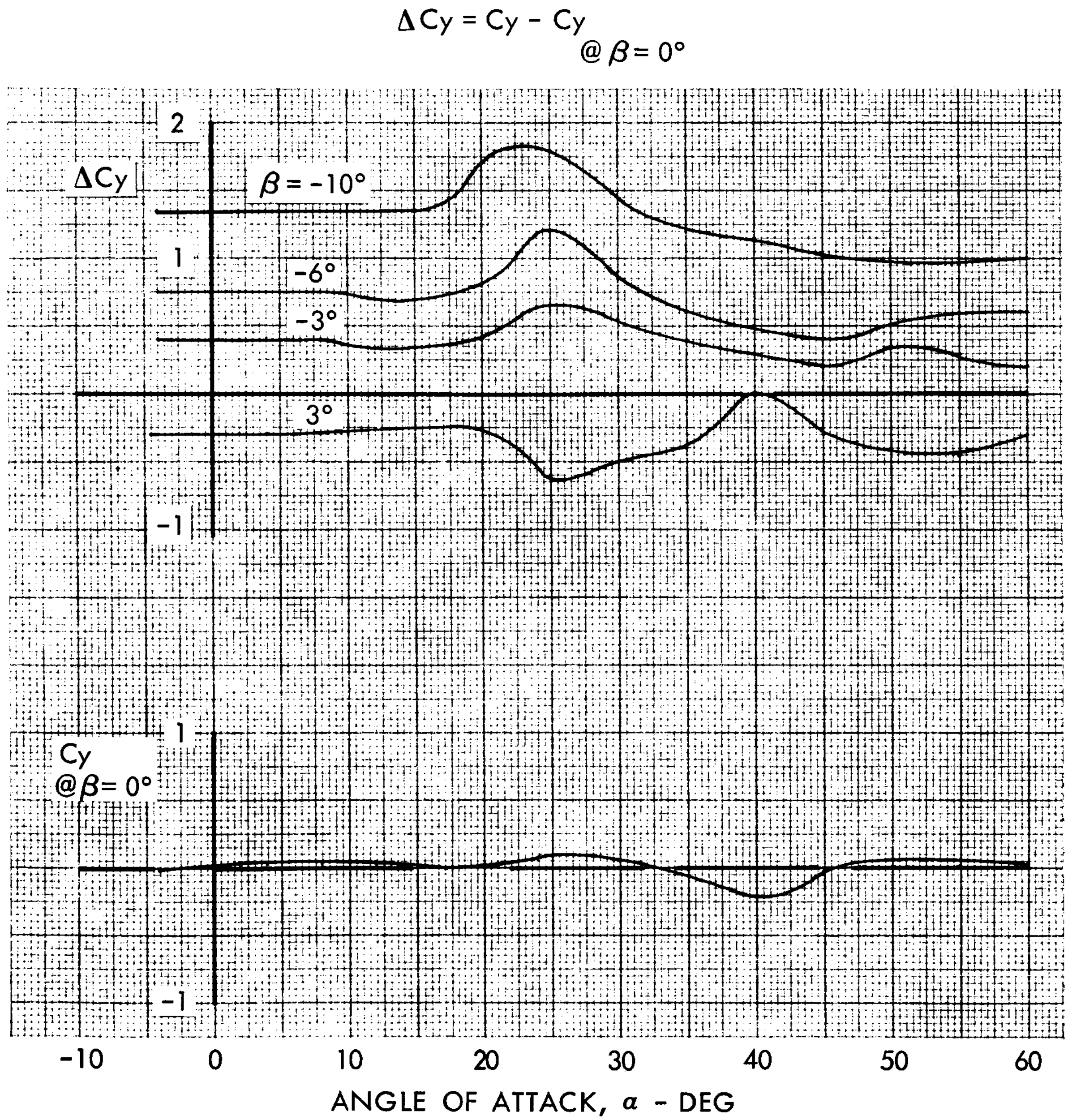

Figure 7. Effect of Angles of Attack and Sideslip on Side Force and Yawing and Rolling Moment Coefficients for Launch-Abort Configuration (Sheet 1 of 3)

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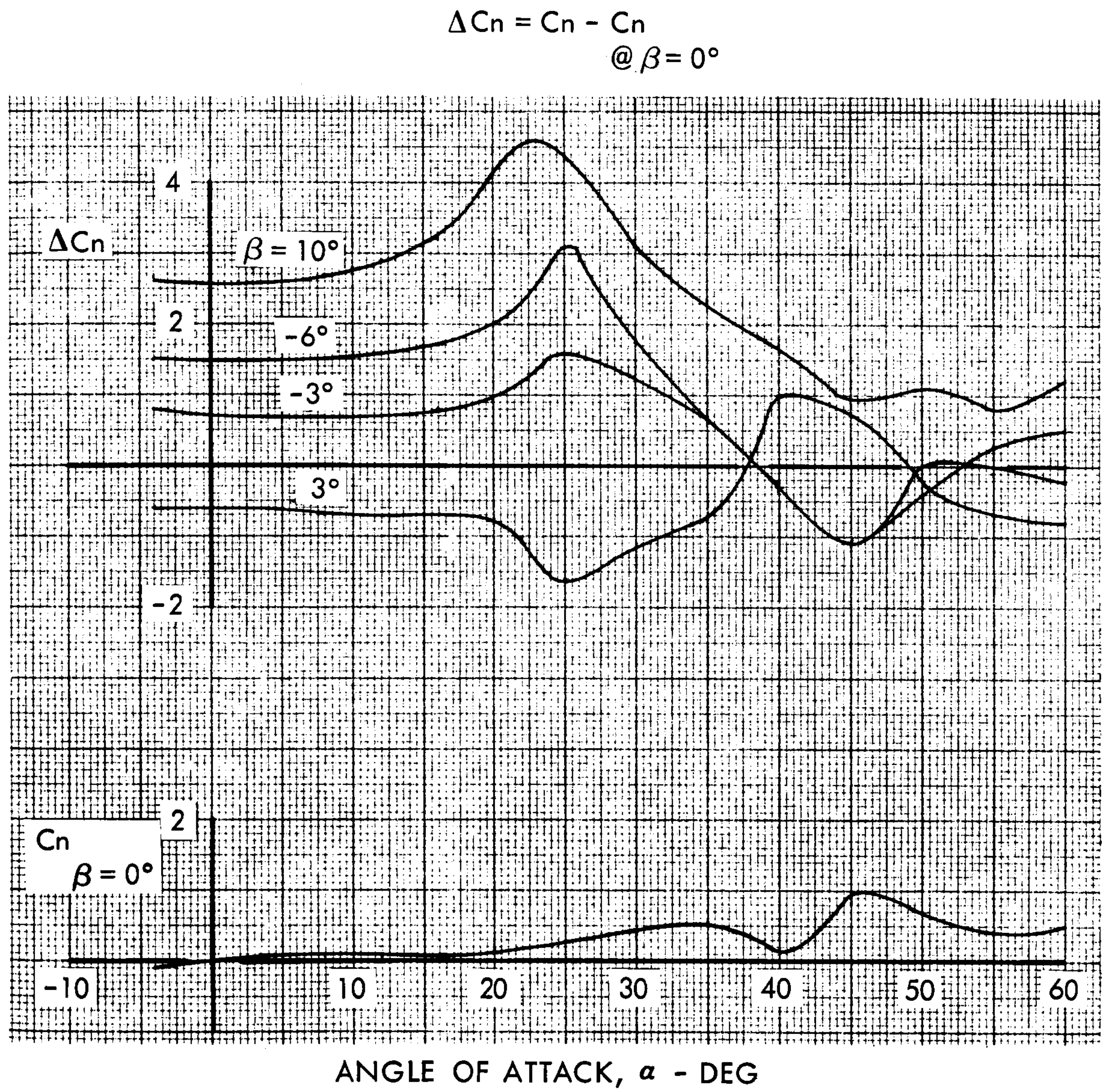

Figure 7. Effect of Angles of Attack and Sideslip on Side Force and Yawing and Rolling Moment Coefficients for Launch-Abort Configuration (Sheet 2 of 3)

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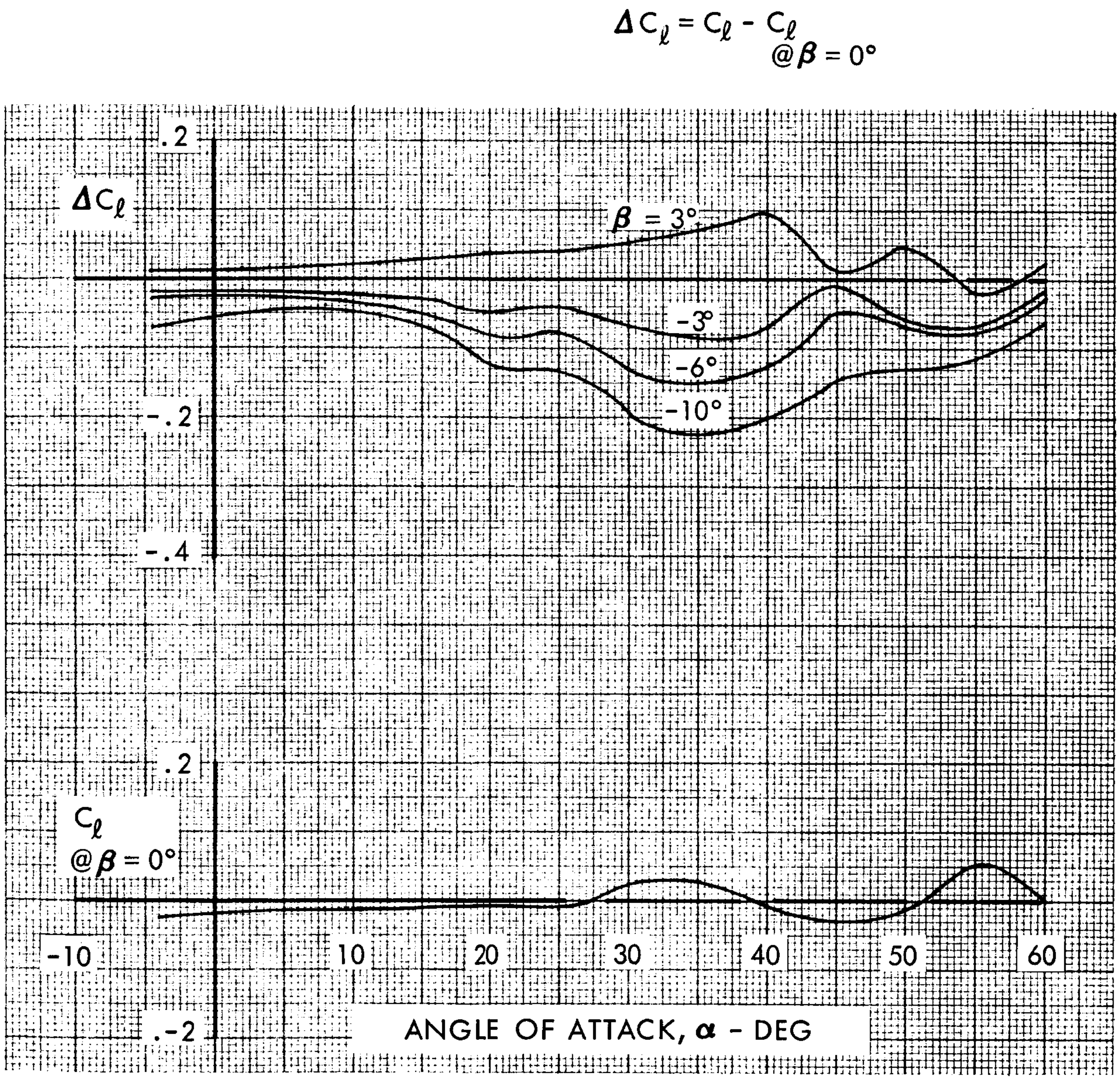

Figure 7. Effect of Angles of Attack and Sideslip on Side Force and Yawing and Rolling Moment Coefficients for Launch-Abort Configuration (Sheet 3 of 3)

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IV. CONCLUSIONS

The static stability and force characteristics of the launch and launch-abort configurations of a 0.02-scale model of the Saturn C-1 launch vehicle with Apollo payload have been investigated in the NACAL wind tunnel for Mach number 0.31 at angles of attack from -4 to 60 degrees. The results of this investigation indicate the following conclusions:

1. The effect of roll attitude on the resultant aerodynamic characteristics is essentially negligible.

2. The variation of normal force characteristics of both configurations with angle of attack is linear to $\alpha = 35$ degrees. The pitching moments are linear to about $\alpha = 10$ degrees.

3. At angles of attack greater than 20 degrees, a sudden peak in side force and related components occur which is associated with low Reynolds number and high angle-of-attack separation phenomena.

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V. SYMBOLS

A_b	Model base area (used for computing base axial force), 0.1364 ft^2
C_A	Axial force coefficient with base axial force removed, $(C_{A_{total}} - C_{A_B})$
$C_{A_{total}}$	Axial force coefficient (including base effects), axial force/qS
C_{A_B}	Base axial force coefficient, $- C_{P_B} A_b/S$
C_ℓ	Rolling moment coefficient, rolling moment/qSD
C_m	Pitching moment coefficient about reference moment center, pitching moment/qSD.
$\bar{C}_m$	Composite pitching moment coefficient, $\bar{C}_m = \sqrt{C_m^2 + C_n^2}$
C_{m_α}	Slope of pitching moment coefficient versus angle of attack, 1/degrees
C_n	Yawing moment coefficient about reference moment center, yawing moment/qSD
C_N	Normal force coefficient, normal force/qS
$\bar{C}_N$	Composite normal force coefficient, $\bar{C}_N = \sqrt{C_N^2 + C_Y^2}$
C_{N_α}	Slope of normal force coefficient versus angle of attack, 1/degrees
C_{P_B}	Base pressure coefficient, $(P_b - P_\infty)/q$
C_Y	Side force coefficient, side force/qS
D	Reference length (booster frontal diameter), 0.4283 ft

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M	Free-stream Mach number
P_b	Model base pressure, lb/ft^2
P_∞	Free-stream static pressure, lb/ft^2
q	Free-stream dynamic pressure, lb/ft^2
R_N	Free-stream Reynolds number per ft
S	Reference area (booster frontal area), 0.1440 ft^2
X_{cp}/D	Center of pressure location measured in reference diameters from the base, positive forward, $X_{cp}/D = \frac{C_m}{C_N} + \frac{\bar{X}}{D}$
$\overline{X}$	Location of reference moment center measured from the model base, 0.389 diameters
α	Angle of attack, degrees
$\bar{\alpha}$	Composite angle of attack, $\cos \bar{\alpha} = \cos \alpha \cos \beta$
β	Angle of sideslip, degrees
ϕ	Angle of roll, degrees

The subscript $\alpha = 0$ denotes conditions existing at zero angle of attack.

[redacted]

VI. REFERENCES

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2. Polhamus, E. C. Effect of Flow Incidence and Reynolds Number on Low-Speed Aerodynamic Characteristics of Several Noncircular Cylinders with Application to Directional Stability and Spinning. NACA TN 4176 (January 1958).

3. Static Stability and Force Characteristics of a 0.02-Scale Model of the Saturn C-1 Launch Vehicle with Apollo Payload for the Mach Number Range 0.7 to 3.5. NAA/S&ID SID 62-1391.

4. Static Stability and Force Characteristics of a 0.02-Scale Model of the Saturn C-1 Launch Vehicle with Apollo Payload for the Mach Number Range 3.5 to 8.0. NAA/S&ID SID 62-1437.

5. Static Stability and Force Characteristics of a 0.02-Scale Model of the Saturn C-1 Launch Vehicle with Apollo Payload for the Mach Number Range 0.4 to 3.5. NAA/S&ID SID 62-1468.

6. Test and Model Information for Wind Tunnel Tests of a 0.02-Scale Force Model (FSL-1) of the Apollo in the NACAL Wind Tunnel. NAA/S&ID SID 62-669.

7. Wykes, J. H., G. R. Casteel, and R. A. Collins. An Analytical Study of the Dynamics of Spinning Aircraft, Part I, Flight Test Data Analysis and Spin Calculations. WADC TR58-381 (December 1958).